Claims:

What is claimed is:

1. A semiconductor multi-layered structure having non-uniform quantum dots formed without requiring lattice strain, characterized in that:

the structure has at least one layer of such quantum dots and;

the quantum dots in the layer are non-uniform quantum dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition.

2. A semiconductor multi-layered structure having non-uniform quantum dots, characterized in that:

it is of a double hetero junction structure comprising an active layer, and a pair of clad layers laid on opposite sides of the active layer and larger in forbidden band than the active layer, and

the active layer includes at least one layer of non-uniform quantum dots formed without requiring lattice strain.

3. A semiconductor multi-layered structure having non-uniform quantum dots as set forth in claim 3, characterized in that the quantum dot layer included in the active layer is formed of non-uniform quantum dots composed of compound semiconductor and different in one or both of size and compound semiconductor composition.

4. A semiconductor multi-layered structure having non-uniform quantum dots as set forth in claim 2 or claim 3, characterized in that it is so structured that a plurality of such non-uniform quantum dot layers are embedded in the active layer.

5. A semiconductor multi-layered structure having non-uniform quantum dots as set forth in any one of claims 2 to 4, characterized in that:

the quantum dots are made of InAs or $Ga_xIn_{1-x}As$ (where $0 < x$

$\leqq$ 0.6); and

the active layer is made of one of materials selected from the class consisting of InP, $Al_xIn_{1-x}As$ (where x = 0.27 to 0.65 and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV), $Ga_xIn_{1-x}As_yP_{1-y}$ (where $0 < x < 1$ and $0 < y < 1$), and $Al_uGa_vIn_wAs$ (where u + v + w = 1, and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV).

6. A semiconductor multi-layered structure having non-uniform quantum dots as set forth in any one of claims 2 to 5, characterized in that:

the semiconductor multi-layered structure having the non-uniform quantum dots has a substrate made of InP;

the quantum dots are made of InAs or $Ga_xIn_{1-x}As$ (where $0 < x \leqq 0.6$);

the active layer is made of $Al_xIn_{1-x}As$ (where x = 0.27 to 0.40 and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV) or $Al_uGa_vIn_wAs$ (where u + v + w = 1, and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV); and

the clad layers are made of $Al_xIn_{1-x}As$ (where x = 0.42 to 0.48 and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV) or $Al_xGa_yIn_zAs$ (where x + y + z = 1, and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV).

7. A semiconductor multi-layered structure having non-uniform quantum dots as set forth in any one of claims 2 to 6, characterized in that the active layer is lattice-matching with the clad layers.

8. A light emitting diode using a semiconductor multi-layered structure having non-uniform quantum dots, characterized in that:

it comprises a p-type semiconductor layer and an n-type semiconductor layer which together form a pn diode; and a layer of non-uniform quantum dots contained in at least one of the semiconductor layers and formed without requiring lattice strain,

whereby injecting current into said pn diode causes the non-uniform quantum dots to be excited, thereby emitting light therefrom in a multi of predetermined wavelengths.

9. A light emitting diode using a semiconductor multi-layered structure having non-uniform quantum dots, characterized in that:

it comprises an active layer containing a semiconductor multi-layered structure having non-uniform quantum dots formed without requiring lattice strain; and

a double hetero junction structure comprising the active layer and clad layers formed at opposite sides of the active layer and larger in forbidden band than the active layer,

whereby injecting current into the double hetero junction structure causes the non-uniform quantum dots to be excited, thereby emitting light in a muti of predetermined wavelengths.

10. A light emitting diode using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in claim 8 or claim 9, characterized in that the quantum dots are non-uniform quantum dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition.

11. A light emitting diode using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in claim 8 or claim 9, characterized in that said wavelengths are emission wavelengths including at least wavelengths of any of ultraviolet light, visible light, and infrared light including a 1.3 μ m band and a 1.5 μ m band.

12. A light emitting diode using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in any one of claims 8 to 10, characterized in that said light emitting diode has a substrate made of InP; and said quantum dots are made of InAs or $Ga_xIn_{1-x}As$ (where $0 < x \leqq 0.6$).

13. A light emitting diode using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in any one of claims 9 to 12, characterized in that

said quantum dots are made of InAs or $Ga_xIn_{1-x}As$ (where $0 < x \leqq 0.6$); and

said active layer is made of one of materials selected from the class consisting of InP, $Al_xIn_{1-x}As$ (where x = 0.27 to 0.65 and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV), $Ga_xIn_{1-x}As_yP_{1-y}$ (where $0 < x < 1$ and $0 < y < 1$), and $Al_uGa_vIn_wAs$ (where u + v + w = 1, and it has a forbidden band at room temperature of 0.95 eV to 1.9 eV).

14. A light emitting diode using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in any one of claims 9 to 13, characterized in that:

the light emitting diode has a substrate made of InP;

the quantum dots are made of InAs or $Ga_xIn_{1-x}As$ (where $0 < x \leqq 0.6$);

the active layer is made of $Al_xIn_{1-x}As$ (where x = 0.27 to 0.40 and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV) or $Al_uGa_vIn_wAs$ (where u + v + w = 1, and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV); and

the clad layers are made of InP.

15. A semiconductor laser diode using a semiconductor multi-layered structure having non-uniform quantum dots, characterized in that:

it comprises an active layer containing at least one layer of non-uniform quantum dots formed without requiring lattice strain; and

a double hetero junction structure comprising the active layer and clad layers formed at opposite sides of the active layer and larger in forbidden band than the active layer,

whereby injecting current into the double hetero junction

structure causes the non-uniform quantum dots to be excited, thereby bringing about laser oscillations in a multi of predetermined wavelengths.

16. A semiconductor laser diode using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in claim 15, characterized in that the quantum dots in the layer are non-uniform quantum dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition.

17. A semiconductor laser diode using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in claim 15, characterized in that said wavelengths are laser oscillation wavelengths including at least wavelengths of any of ultraviolet light, visible light, and infrared light including a 1.3 μ m band and a 1.5 μ m band.

18. A semiconductor laser diode using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in any one of claims 15 to 17, characterized in that

the semiconductor laser diode has a substrate made of InP;

the quantum dots are made of InAs or $Ga_xIn_{1-x}As$ (where $0 < x \leqq 0.6$);

the active layer is made of $Al_xIn_{1-x}As$ (where x = 0.27 to 0.40 and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV) or $Al_uGa_vIn_wAs$ (where u + v + w = 1, and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV); and

the clad layers are made of $Al_xIn_{1-x}As$ (where x = 0.42 to 0.48 and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV) or $Al_xGa_yIn_zAs$ (where x + y + z = 1, and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV).

19. A semiconductor laser diode using a semiconductor multi-layered structure having non-uniform quantum dots as set forth

in any one of claims 15 to 18, characterized in that the active layer is lattice-matching with the clad layers.

20. A semiconductor light amplifier using a semiconductor multi-layered structure having non-uniform quantum dots, characterized in that:

it comprises an active layer containing at least one layer of non-uniform quantum dots formed without requiring lattice strain; and

a double hetero junction structure comprising the active layer and clad layers formed at opposite sides of the active layer and larger in forbidden band than the active layer,

whereby injecting current into the double hetero junction structure causes the non-uniform quantum dots to be excited, thereby amplifying light in a multi of predetermined wavelengths incident externally of the double hetero junction structure.

21. A semiconductor light amplifier using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in claim 20, characterized in that the quantum dots in the layer are non-uniform quantum dots individually composed of compound semiconductor and different in one or both of size and compound semiconductor composition.

22. A semiconductor light amplifier using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in claim 20, characterized in that said wavelengths are amplification wavelengths including at least wavelengths of any of ultraviolet light, visible light, and infrared light including a 1.3 μ m band and a 1.5 μ m band.

23. A semiconductor light amplifier using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in any one of claims 20 to 22, characterized in that

the semiconductor light amplifier has a substrate made of InP;

the quantum dots are made of InAs or $Ga_xIn_{1-x}As$ (where $0 < x \leqq 0.6$);

the active layer is made of $Al_xIn_{1-x}As$ (where x = 0.27 to 0.40 and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV) or $Al_uGa_vIn_wAs$ (where u + v + w = 1, and it has a forbidden band at room temperature of 0.95 eV to 1.24 eV); and

the clad layers are made of $Al_xIn_{1-x}As$ (where x = 0.42 to 0.48 and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV) or $Al_xGa_yIn_zAs$ (where x + y + z = 1, and it has a forbidden band at room temperature of 1.3 eV to 1.46 eV).

24. A semiconductor light amplifier using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in any one of claims 20 to 23, characterized in that the active layer is lattice-matching with the clad layers.

25. A method of making a semiconductor device using a semiconductor multi-layered structure having non-uniform quantum dots in a non-uniform quantum dot structure, characterized in that it includes the step of fabricating the non-uniform quantum dot structure for the semiconductor device by an epitaxial growth process that does not require lattice strain in forming non-uniform quantum dots.

26. A method of making a semiconductor device using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in claim 25, characterized in that said semiconductor device is any one of a light emitting diode, a semiconductor laser diode and a semiconductor light amplifier.

27. A method of making a semiconductor device using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in claim 25 or claim 26, characterized in that said epitaxial growth process comprises any one of MOCVD, MBE, gas source MBE and MOMBE processes and a layer of the non-uniform

quantum dots is fabricated by a droplet epitaxial growth process which does not require lattice strain in forming non-uniform quantum dots.

28. A method of making a semiconductor device using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in claim 27, characterized in that the non-uniform quantum dot layer is formed by an auto-terminating mechanism in said droplet epitaxial growth process.

29. A method of making a semiconductor device using a semiconductor multi-layered structure having non-uniform quantum dots as set forth in any one of claims 25 to 28, characterized in that said epitaxial growth process is MOCVD and the non-uniform quantum dot layer is formed by droplet epitaxial growth at a growth temperature lower than that at which other growth layers in the structure are formed.